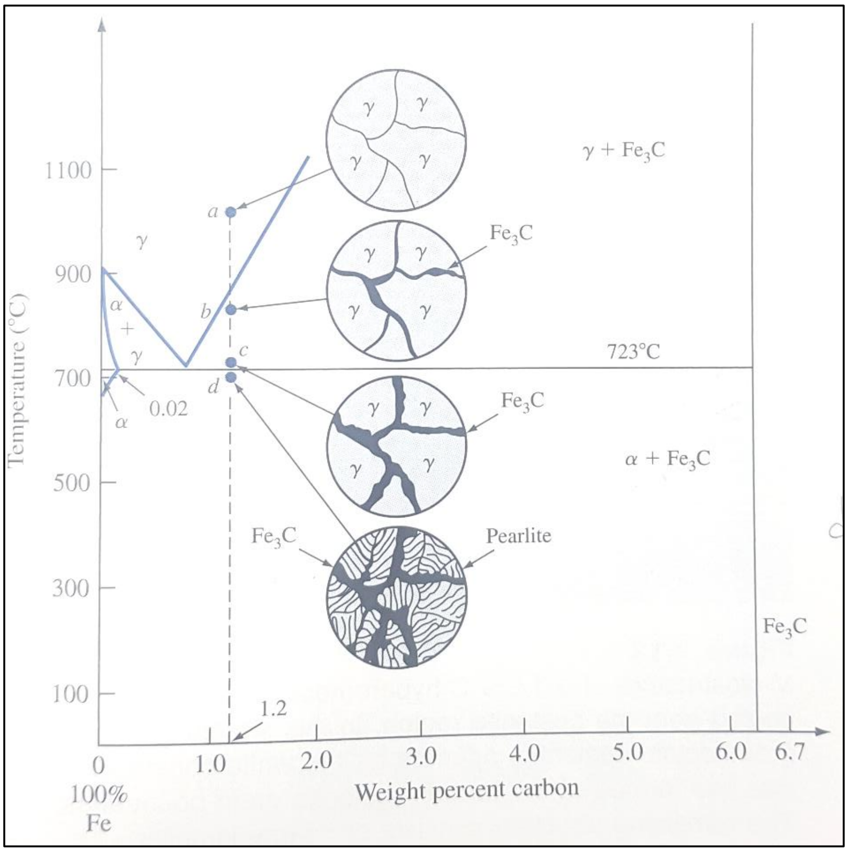
Advanced Construction Materials

Homework #4

Due: May 21st at 6 pm

1. A hypoeutectoid plain-carbon steel that was slow-cooled from the austenitic region to room temperature contains 9.1 wt% eutectoid ferrite (ferrite in perlite). Assuming no change in structure on cooling from just below the eutectoid temperature to room temperature, what is the carbon content of the steel? **(20pt)**

2. If a sample of a 1.2 percent C plain-carbon steel (hypereutectoid steel) is heated to about 950˚C and held for a sufficient time, its structure will become essentially all austenite (point *a* in below Figure). With further slow cooling to point *c* of the Figure, which is just above 723˚C, more proeutectoid cementite will be formed at the austenite grain boundaries. Calculate the weight percentage of the proeutectoid cementite at point *c* and *d*, respectively. **(20pt)**



3. From LJ potential, interaction energy (u_{total}) between two atoms can be defined. In case of FCC structure, equation for bulk modulus (B) of FCC crystal can be formulated as below:

$$B = \frac{\sqrt{2}}{9R^*}\left(\frac{\partial^2 u_{tot}}{\partial R^2}\right)_{R^*}$$

Define the equation for a bulk modulus of BCC crystal. **(20pt)**

4. Jennite is a crystal that has similar nanostructure of C-S-H (main binding phase in cement paste). Crystal structure of Jennite is Triclinic which has 21 independent elastic constants (C_{ij}). Below is a list of the elastic constants (GPa unit) of Jennite published in *Moon et al. in Cement and Concrete Research 2015*.

C_{11}	100.0	C_{23}	41.7	C_{36}	− 1.4
C_{12}	49.0	C_{24}	3.0	C_{44}	23.3
C_{13}	46.6	C_{25}	− 4.9	C_{45}	− 3.2
C_{14}	− 6.7	C_{26}	− 6.9	C_{46}	1.8
C_{15}	4.9	C_{33}	78.8	C_{55}	27.0
C_{16}	− 3.0	C_{34}	0.3	C_{56}	− 0.6
C_{22}	127.5	C_{35}	− 6.0	C_{66}	41.1

Using the below two relations, calculate a bulk modulus of Jennite crystal. **(20pt)**

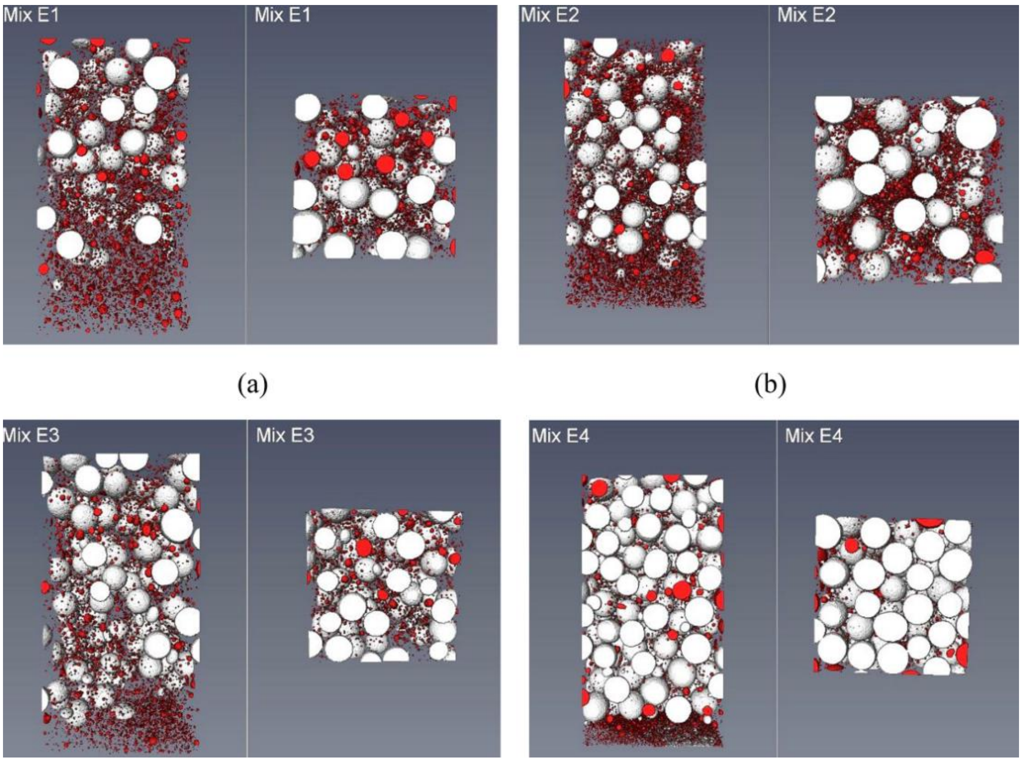
$$U = \frac{1}{2}B\cdot\delta^2$$ where δ is volumetric strain

$$U = \frac{1}{2}\sum_{i=1}^{6}\sum_{j=1}^{6}C_{ij}e_i e_j$$ where $e_1 = e_2 = e_3 = \frac{1}{3}\delta$

5. Lightweight concrete was developed based on the combination of ultra-high performance concrete (UHPC) and expanded polystyrene (EPS). Make plots of Young's modulus of lightweight concrete as a function of replacement rates of EPS (f_i ranging from 0 to 50%) in UHPC. Use Reuss-Voigt bound and Hashin-Strikman bound and discuss its result. **(20pt)**

For simple calculation, use Young's moduli of UHPC and EPS as 20 GPa and 1 GPa and Shear moduli of UHPC and EPS as 20 GPa and 1 GPa, respectively.

FYI, Below is micro-CT image of developed composites. E1, E2, E3, and E4 mix has EPS vol% of 16, 25, 36, and 45%, respectively. Images from *Dixit et al. Cement and Concrete Composites, 2019*.



(a) (b)